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DISCLAIMER

Analysis of Statically Indeterminate Tie-Down Systems

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ABSTRACT

The purpose of this analysis is to propose and qualify a design of the tie-down system for the High Level Waste (HLW) pump/agitator transport container.

A design of the tie-down system was proposed for the HLW pump/agitator transport box subjected to the transportation loads defined in the IAEA safety guide [1990]. The proposed tie-down system consists of two groups of four tension members and each group is anchored to the package at different elevations. This arrangement has the advantage of reducing the forces in the tension members significantly; however it also makes the system statically indeterminate and difficult to analyze. The analytical method discussed in the IAEA safety guide and the Advisory Material [1996] is not applicable to the proposed HLW transport tie-down system. Therefore, a nonlinear static analysis was performed to qualify the tie-down system.

The analysis shows that the tie-down system can prevent both translation and rotation motions of an HLW pump/agitator transport container during shipping. The analysis shows that the maximum stresses in the tie-down lugs and the container wall caused by the tie-down loads are within the allowable limits.

DESCRIPTION OF TIE-DOWN SYSTEM

Figure 1 shows the arrangement of the tie-down system when it is in use. The proposed design of the tie-down system consists of 8 tension members. The upper ends of the four upper tension members are anchored to the upper tie-down lugs at the elevation of 14' 6 $^{1}/4$" measured from the bottom of the box. On the other hand, the upper ends of the four lower tension members are anchored to the lower tie-down lugs at the elevation of 7' 6". The lower ends of both the upper and lower tension members are fastened to the same four anchor points at the truck trailer bed.

The chocks made of four metal blocks are used to restrict the horizontal movement of the container. These chocks are fastened to the truck trailer bed and abut the bottom of the container. The tension members can either be ropes or steel chains.
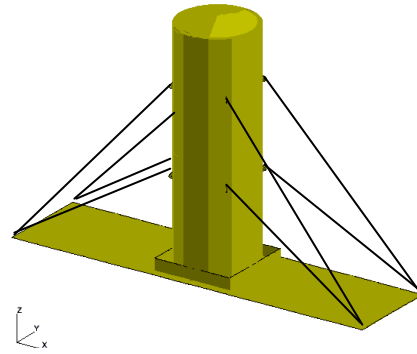

Figure 1. Configuration of HLW Pump/Agitator Transport Container and Tie-Down system

ANALYSIS

The structural response of the tie-down system was evaluated by performing a nonlinear static finite-element analysis. The ABAQUS/Standard computer code [HKS, 1998] was used to perform the computations. The finite-element meshes were generated using the MSC/PATRAN computer program [MacNeal-Schwender, 1999].

Methodology

The HLW transport container is used for on-site transport. An inspection of the transport route did not find any significant bad road condition. Thus, the HLW transport is expected to experience much less severe loads than a state-to-state or international transport. However, for conservatism, the loads defined in the IAEA Safety Guide for international transport are used to qualify the proposed tie-down system.

The G loads are defined in the IAEA Safety Guide. Since these loads usually do not occur simultaneously, it is complicated to determine their combined effect properly. The method used in the IAEA Safety Guide and the Advisory Material for the Regulations for the Safe Transport of Radioactive Materials are adopted in the present analysis. This method provides the upper bound value of the tensile forces in the tie-down members. The method basically consists of the following three steps:

(1). Step 1: The forces in the tension members are calculated by assuming the longitudinal and vertical loads acting simultaneously. This load combination is

assumed to cause the package to rotate as a rigid body and is just on the point of tipping about the axis in the lateral direction and tangent to its bottom edge. The chock is assumed to be capable of preventing the longitudinal translation but not rotations of the package.

(2). Step 2: The forces in the tension members are calculated by assuming the lateral and vertical loads acting simultaneously. This load combination is assumed to cause the package to rotate as a rigid body and is just on the point of tipping about the axis in the longitudinal direction and tangent to its bottom edge. The chock is assumed to be capable of preventing the laterals translation but not rotation of the package.

(3). Step 3: The resultant forces in the tension members are calculated by linearly combined the forces calculated in Steps 1 and 2.

Finite-Element Model

The finite-element method is used to determine both the forces in the tension members and the resulting stresses in the tie-down lugs and box wall. Since analysis involves both the deformations and rigid-body motions of the structure, great care must be taken to prevent numerical singularities.

The finite-element model includes the components such as the cylindrical wall and its stiffeners, solid rings, floor plate, bottom plate, roof, pump/agitator support and adapter plates, pump, and tie-down lugs. These components are represented by using the shell, solid, and beam elements, respectively. The tension members of the tie-down system are modeled by using truss elements. The analytical option of "No Compression" is included in the model to ensure that the tension members will not take compression. The truss elements are three dimensional and thus its lack of resistance to the tensile and rotational loads will result in numerical singularities in certain degrees of freedom in translation and rotation. To eliminate these numerical singularities, some fictitious 3-D spring elements are added to the model. Since the stiffness of these springs is very low, the affect on the accuracy of the analytical results is insignificant.

Since the same finite-element model will also be used for a separate dynamic analysis, the structure of the transport container was modeled in rather details. The stresses and deformations in the remaining components are not of concern in justifying the structural integrity of the transport system for both tie-down loads. Therefore, they are not included in the model. However, the weights of the remaining components will affect the G loads in the tie-down analysis and therefore the equivalent densities are used in the model.

Figure 2 shows the finite-element of the HLW pump/agitator transport container and its tie-down system.
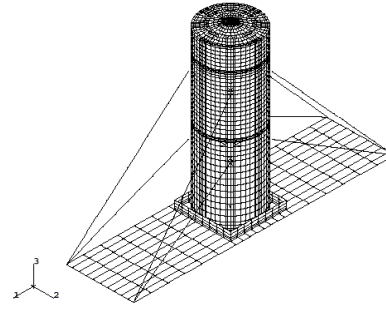

Figure 2. Finite-Element Model of HLW Pump/Agitator Transport Container and Tie-Down System

Calculations of Tensile Forces for Combined Longitudinal and Vertical Loads

Applied Loads and Boundary Conditions

To model the load combination for Step 1Anaysis discussed earlier, the gravitational loads (G loads) are applied as follows: The gravitational loads of 2 G's are applied in both the positive X (longitudinal) and Z (vertical) directions of the finite-element model. In addition, the gravitational load of 1 G is applied in the negative Z direction.

To model the boundary conditions of Step 1 Analysis, the node on the bottom edge of the box model shown as Point A in Figure 2 is constrained in the following degrees of freedom:

$$UX, UY, UZ, RX, RZ = 0.$$

Force in Tension Members

The maximum value of the tensile stresses in the tension members is 74,788 lb/in^2. Since the diameter of the tension members is assumed to be 3/8", the maximum tensile force in the tension members is calculated as follows.

$$F_x = \frac{p}{4}d^2s = \frac{p}{4}\left(\frac{3}{8}\right)^2 \times 74788 = 8260 \text{ lbs}$$

Stresses in Tie-Down Lugs

The highest stress area of the tie-down lugs has the following values of the von Mises stresses:

> von Mises stress on one side of the lug = 29,698.0 psi
>
> von Mises stress the other side of the lug = 28,672.0 psi

Thus, the von Mises stresses across the lug thickness exceed the yield stress of stainless steel

304L material, 25,000 psi at a certain location. However, the tie-down lugs will not rupture at these stresses.

Stresses in Container Wall

The maximum value of the von Mises stress on the wall of the transport box is 14,297.0 psi, which is below the material yield stress of 25,000 psi.

Figure 3 shows the deflected shape of the HLW transport system (magnified by 50 times).
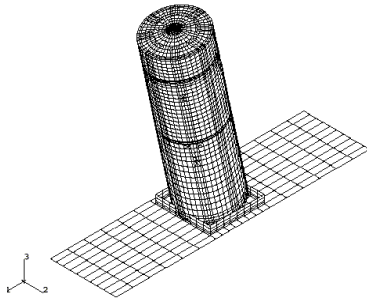
Figure 3. Deflected Shape of the HLW Pump/Agitator Transport System in X Direction (magnified by 50 times)

Calculations of Tensile Forces for Combined Lateral and Vertical Loads

Applied Loads and Boundary Conditions

To model the load combination for Step 2 Analysis, the gravitational loads (G loads) are applied as follows: The gravitational load of 1 G's is applied in the positive X (lateral); whereas the gravitational load of 2 G's are applied in the positive Z (vertical) directions of the finite-element model. In addition, the gravitational load of 1 G is applied in the negative Z direction.

To model the boundary conditions for Step 2 Analysis, the node on the bottom edge of the box model shown as Point B in Figure 2 is constrained in the following degrees of freedom:

UX, UY, UZ, RY, RZ = 0.

Force in Tension Members

The maximum value of the tensile stresses in the tension members is 116,750.0 lb/in^2. Since the diameter of the tension members is assumed to be 3/8", the maximum tensile force in the tension members is calculated as follows.

$$F_y = \frac{p}{4}d^2 s = \frac{p}{4}\left(\frac{3}{8}\right)^2 \times 116750 = 12,895.0 \text{ lbs}$$

Stresses in Tie-Down Lugs

The maximum value of the von Mises stresses in the tie-down lugs is 18,937.0 psi, which is less than the material yield stress of 25,000 psi.

Stresses in Box Wall

The maximum value of the von Mises stress on the wall of the transport box is 9,111.0 psi, which is below the material yield stress of 25,000 psi.

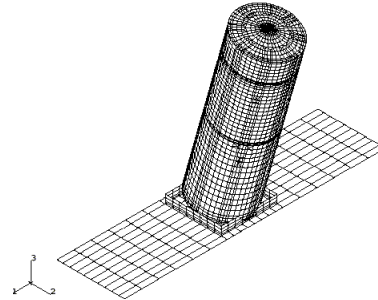Figure 4 shows the deflected shape of the tie-down system (magnified by 10 times).

Figure 4. Deflected Shape of HLW Pump/Agitator Transport System in Y Direction (magnified by 10 times)

Calculations of Tensile Forces for Combined Longitudinal, Lateral and Vertical Loads

Force in Tension Members

To model the load combination for Step 3 Analysis discus, the tensile forces are linearly combined to obtain the total tensile forces for the combined longitudinal, lateral and vertical loads as follows:

$$F = F_x + F_y = 8260 + 12895 = 21,155.0 \text{ lbs.}$$

Stresses in Tie-down Lugs

The maximum von Mises stress for the combined loads in the three directions is:

$$S = S_x + S_y = 29,698.0 + 18,937.0 = 48,635.0 \text{ psi.}$$

The above stress for the normal operating condition is within the allowable limit of twice the yield stress of stainless steel 304L material (50,000 psi) in accordance with the ASME Code, Section III [1992].

Stresses in Box Wall

The maximum von Mises stress for the combined loads in the three directions is:

$$S = S_x + S_y = 14,297.0 + 9,111 = 23,408.0 \text{ psi}$$

The above stress is less than the material yield stress of 25,000 psi.

REFERENCES

IAEA Safety Guides, Safety Series NO.37, Appendix VII, Third Edition, "Acceleration Values and Calculation Methods for Package Tie-Down Forces," 1990.

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ASME Code, 1992 ASME Boiler & Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," American Society of Mechanical Engineers, New York, NY (1992)